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MICROGRID SOLUTIONS FOR INSULAR POWER SYSTEMS IN THE OUTBACK OF AUSTRALIA

ROZWIĄZANIA HYBRYDOWE TYPU MICROGRID DLA IZOLOWANYCH SYSTEMÓW ENERGETYCZNYCH W INTERIORZE POŁUDNIOWEJ AUSTRALII

Abstract: In countries, such as Australia, with often vast distances between settlements and the mains power grid, insular power systems are the only solution. The most common of them is diesel generation that is relatively inexpensive, however it can have long term financial and environmental implications such as a large production of green house gases (GHGs). In the paper on an example of a remote water pump station, we compare microgrids of diesel generation only, combination of it with solar generation and an addition to the latter of a battery storage. It is demonstrated that addition of renewable energy to diesel generation can be a viable alternative for insular power systems, resulting in drastic reduction of diesel fuel consumption, emission of GHGs and reduction of total operating and maintenance costs.

Streszczenie: W krajach takich jak Australia, często ogromne odległości między osiedlami i siecią elektroenergetyczną, wyspowe systemy zasilania są jedynym rozwiązaniem. Najczęstszym z nich jest generator Diesla, który jest stosunkowo tani, jednak może mieć długoterminowe skutki finansowe i środowiskowe, takie jak duża produkcja zielonych gazów (GHG). W artykule porównano, na przykładzie stacji zdalnej pompy wodnej mikrosieci generację silników wysokoprężnych, połączonych z instalacją solarną oraz systemem baterii do przechowywania energii. Wykazano, że oddanie energii odnawialnej do układu napędowego może być realną alternatywą dla wyspiarskich systemów energetycznych, w wyniku drastycznego zmniejszenia zużycia oleju napędowego, emisji gazów cieplarnianych i zmniejszenia całkowitych kosztów eksploatacji i utrzymania.

1. Introduction

One of the basic needs in remote areas of Australia is energy. Often, remote locations are not within close proximity to a mains power grid. An easy solution to providing power in remote areas is diesel generation. Diesel generation is not capital intensive; however, it can have long term negative financial impacts as well as producing undesirable amounts of Green House Gases (GHGs). The contribution to GHGs and adverse environmental impacts is the consequence of the excessive consumption of diesel fuel.

Nowadays microgrids (MGs) often combine several different energy sources to act as one generation source, to meet specific electrical demand. A MG can work synchronously with the macrogid (mains power grid) but also needs to have the functionality to operate as an isolated (insular) power system as presented in this paper.

In the paper we analyse a remote area water pump station with two pumps running typically on diesel power generation. This is compared with MGs of a diesel generator coupled with solar generation, and then with an addition of a battery energy storage to the latter.

HOMER [1] Microgrid modelling software by the U.S. National Renewable Energy Laboratory was used in modelling the power source for a dedicated load such as a remote water pump station. HOMER has three main tasks which it performs to allow for analysis of the proposed MG which are simulation, optimisation and sensitivity analysis.

Recent advances in renewables such as solar power, wind farms and battery storage resulted in reduced costs and increase of the reliability.

As a result the main finding of this paper is that diesel power generation can be complemented by renewable energy technologies, drastically reducing diesel fuel usage and GHGs.

The total operating and maintenance costs are also reduced when renewable energy is used because after the initial capital outlay, maintenance is very often minimal for solar panels and battery storage solutions.

2. The system

The paper considers a pump station containing two water pumps and general electrical loads such as lighting and control, with the emphasis on powering the station. It is assumed that the Direct-on-Line (DOL) electric motors startup is used. Two basic centrifugal water pumps are used maintaining a constant flow at a constant pump speed. As the pumps will operate at a constant speed, a constant motor current draw is assumed. The aim of the paper is to focus on the environmental and economic factors associated with operating and maintaining a remote water pump station. Similar environmental and economical studies in the context of using electric vehicles were conducted in [2]. The scope of the paper will include a comparison between the existing and potential microgrid solutions.

3. Microgrids

A microgrid usually consists of several energy sources coupled to a common power bus AC or DC and generally includes the mains grid power supply. By definition MGs do not dictate how many or what the connected power sources are, nor is it defined to be a certain size. Generally a MG must be locally controlled and be able to operate in conjunction with the mains grid and also as an electrically isolated (insular) system as remote power applications are often very far from the mains grid. Types of energy sources include, solar, wind, hydro, batteries, fuel cells and in some cases backup diesel generators. The system often involves complex control which helps maintain power stability including voltage and frequency in the areas. Control systems will also act to manage the power conversion and switching in and out various sources or loads.

4. Microgrid simulation software

HOMER software used in the paper is able to simulate different configurations of power systems and loads and is able to capture data for each hour of a day over one year period. The main limitation of HOMER is that it cannot detect transients for very small time periods but the upside is that model can easily be simulated with minimal computing power. HOMER can simulate different scenarios and configurations which enables a user to come up with a solution that satisfies the user's preferences, is considered fit-for-purpose and has the lowest lifecycle cost. An example of a microgrid with AC and DC buses is shown in Figure 1.

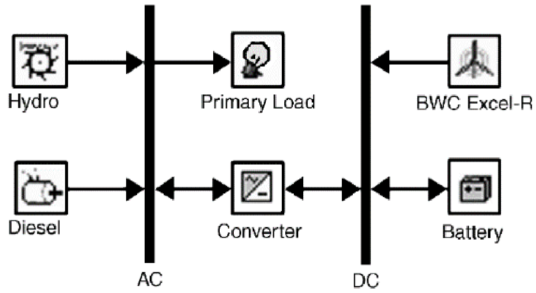

Fig. 1. Microgrid with various power sources

5. Diesel generation

The analysed pump station consists of two pumps drawing water from a storage pond as shown in Figure 2.

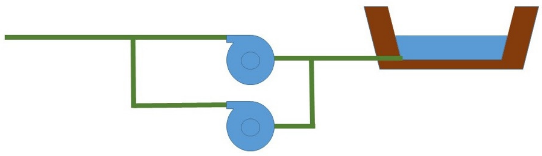

Fig. 2. Representation of two pumps drawing water from a storage pond

Each pump will be powered by a 415 V, 55 kW electric motor. The starting method will be direct-on-line starting or DOL. With DOL the starting current is assumed to be 7.0 times the full load current of the induction motor. This means that each induction motor will need approximately 385 kVA to start.

The ancillary load at the pump station will consist of components such as diesel bowser pumps, battery chargers, lighting, local control hardware and general electrical services. This will be an assumed connected load of 5kW.

For the purpose of this project the total electrical loading will be considered 60 kW as only one pump is required at any one time. Taking into account starting current and other loads the generator selected for analysis will have a prime power delivery capability of 184 kW. Assuming a power factor 0.8 this equates to 230 kVA of required apparent power.

For ease of analysis the pump station will contain two diesel generators connected to a common bus. The generators have the ability to synchronise onto the bus to operate in parallel, if required. The bus will then supply power to water pumps to enable the transportation of water over a distance. The main requirement is to maintain a reliable AC bus at all times.

High load industrial applications such as water pumping stations require reliability. For the purpose of this the two diesel generators will be utilised 50% of the time, alternating at set intervals. This will ensure redundancy under maintenance and/or failure conditions, enabling 24 hours a day operation. For the existing system simulation one 184kW generator and one 60 kW load will be modelled.

The discount rate has been assumed to be 7.0% and the inflation rate of 2.0%. Generator lifecycles are assumed to be 60,000 hours prior to requiring capital replacement or overhaul. Capacity shortage is set to zero as there will be two generators and only one is needed at any one time. Capital purchase cost is estimated at AU$75,000 and replacement cost will also be AU$75,000.

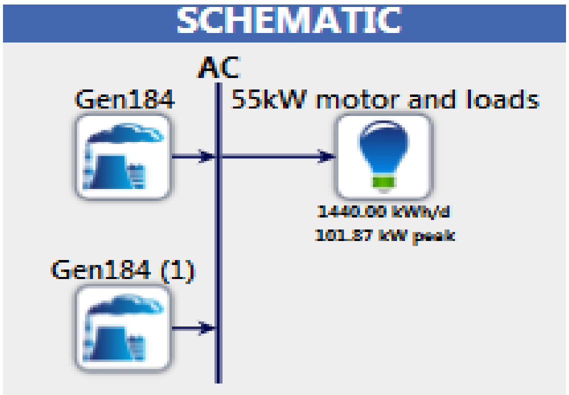

Fig. 3. Schematic of the diesel only system

Diesel fuel price is assumed to be AU$1.50 per litre, which is inclusive of delivery charges. Operation and Maintenance costs (O&M) is assumed to be $10/hr which is AU$87,600 per year. A project lifecycle of 20 years will be modelled. Table 1 shows objective data for diesel only system, extracted from the HOMER simulation.

6. Example of solar data

In [3] solar data in an outback town Oodnadatta (over 1,000 km North from Adelaide) in South Australia was analysed resulting in the mean daily global solar radiation per annum on a horizontal surface of approximately 6.29 kWh/m^2. The mean daily sunshine duration in Oodnadatta is 9.6 hours per day which is comparable to that in Egypt and Saudi Arabia, the two countries with the greatest solar potential. The mean daily sunshine hours in these countries are 11 hours and 8.9 hours, respectively [4, 5]. Similar conditions exist in many outback locations of Australia, making the application of solar power a viable option.

7. Microgrid: diesel/solar

The diesel/solar system was modelled with one diesel generator, described in section 6, and a flat solar panel with the mean daily global solar radiation per annum on a horizontal surface of approximately 5.6 kWh/m^2. This is less than Oodnadatta as in this case the location was Woomera in central South Australia (487 km North from Adelaide).

The diesel generator was scheduled for optimal performance. This means that solar will operate whenever possible and diesel will only be used when the solar panels cannot meet the demand. The system schematic is shown in Figure 4.

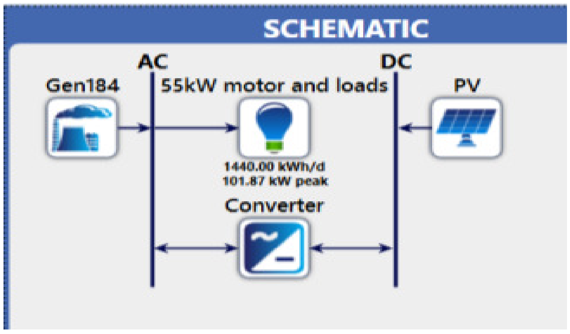

Fig. 4. Schematic of diesel/solar system

Table 1. Objective data for diesel only system

OBJECTIVE DATA							
Cost of Energy (COE) ($/kWh)	Net Present Cost (NPC) ($)	Annualised Operating Cost ($)	Initial Capital Cost ($)	Annual O & M Cost ($)	Diesel Fuel Usage (l/y)	Total Diesel Fuel Usage (l/20y)	Estimated Carbon Emissions (kg/y)
0.696	4.6m	354k	150k	87.6k	175k	3.5m	461k

The capital cost of solar panels was assumed to be \$1 per Watt. O&M costs were assumed to be AU\$10,000 per year. The lifecycle of panels was assumed to be 25 years with a de-rating factor of 80%.
A standard 75 kW inverter (AU\$40,000) with a lifetime of 15 years and efficiency of 90% was used.
The optimal solution included the 184 kW diesel generator, the 75 kW inverter and 200 kW solar panels.
In Table 2, a comparison of diesel only and diesel/solar systems is presented.
Introducing solar panels with no form of energy storage already displays a lower net present cost (NPC), annual operating and maintenance costs, reduced fuel consumption and emissions. The key metric, cost of energy (COE) has also been reduced. The biggest downside to renewable energy solutions is the initial capital cost.

Table 2. Objective data for diesel and diesel/solar systems

OBJECTIVE DATA								
	Cost of Energy (COE) (\$/kWh)	Net Present Cost (NPC) (\$)	Annualised Operating Cost (\$)	Initial Capital Cost (\$)	Annual O & M Cost (\$)	Diesel Fuel Usage (l/y)	Total Diesel Fuel Usage (l/20y)	Estimated Carbon Emissions (kg/y)
Diesel Only	0.696	4.6m	354k	150k	87.6k	175k	3.5m	461k
Diesel /Solar	0.539	3.56m	258k	315k	73.7k	121k	2.4m	318k

8. Microgrid: diesel/solar/battery

The same specifications for diesel generator and solar panels as described previously were maintained. A generic lithium ion 1 kWh 6V battery was used for the simulation. To maintain a 420 V DC bus a string of 70 batteries were placed in series. Ten strings were modelled to provide 70 kWh of storage with 167 Ah of capacity. This makes for a bank of 700 batteries.
A price of AU\$600 per kWh of battery storage was utilised for the HOMER simulation. Operating and maintenance costs were neglected as batteries, once installed, are considered maintenance free.
The HOMER simulation system is shown in Figure 5.
Two dispatch strategies were modelled, load following and cycle charging. The load following only supplies as much energy as is needed. Cycle charging runs generators at full output whenever they are running and charges batteries with excess output.
After experimenting with both models it was found that load following provided the best results so this is the dispatch strategy that will be utilised.

Summary of simulations for the three configurations is shown in Table 3. It shows that by introducing a simple bank of batteries to the microgrid has reduced all the performance indicators except the initial capital investment.

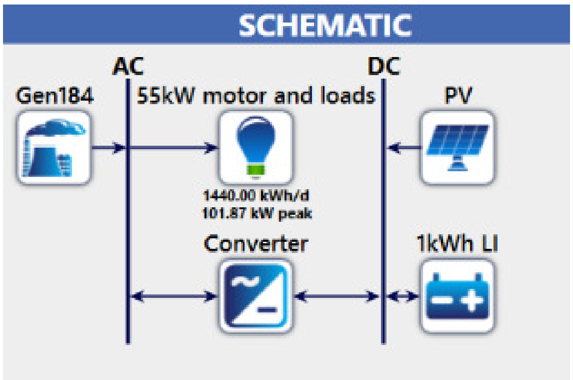

Fig. 5. Schematic of diesel/solar/battery system

9. Conclusions

Overall, the findings of the paper are clear. Renewable energy can be a viable alternative for remote power applications if an effective engineering analysis is performed and results are presented to management in a way that the cost benefits are easily attained, while also the contribution to the world's more sustainable environmental future is taken into account.

Table 3. Objective data for the three system

OBJECTIVE DATA								
	Cost of Energy (COE) ($/kWh)	Net Present Cost (NPC) ($)	Annualised Operating Cost ($)	Initial Capita l Cost ($)	Annual O & M Cost ($)	Diesel Fuel Usage (l/y)	Total Diesel Fuel Usage (l/20y)	Estimated Carbon Emissions (kg/y)
Diesel Only	0.696	4.60m	354k	150k	87.6k	175k	3.5m	461k
Diesel/ Solar	0.539	3.56m	258k	315k	73.7k	121k	2.4m	318k
Diesel/ Solar/ Battery	0.428	2.83m	167k	735k	49.2k	70k	1.4m	185k

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